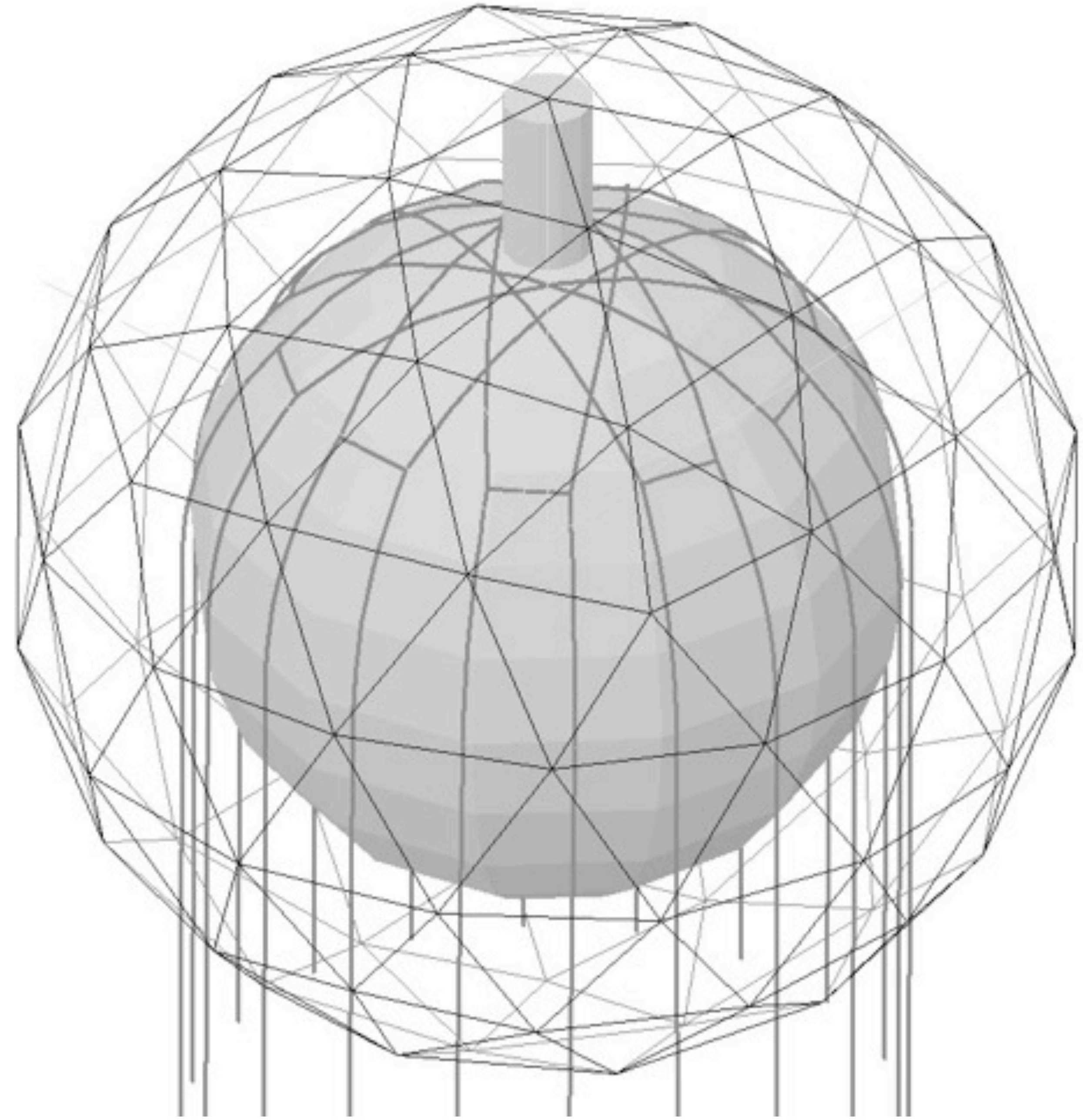
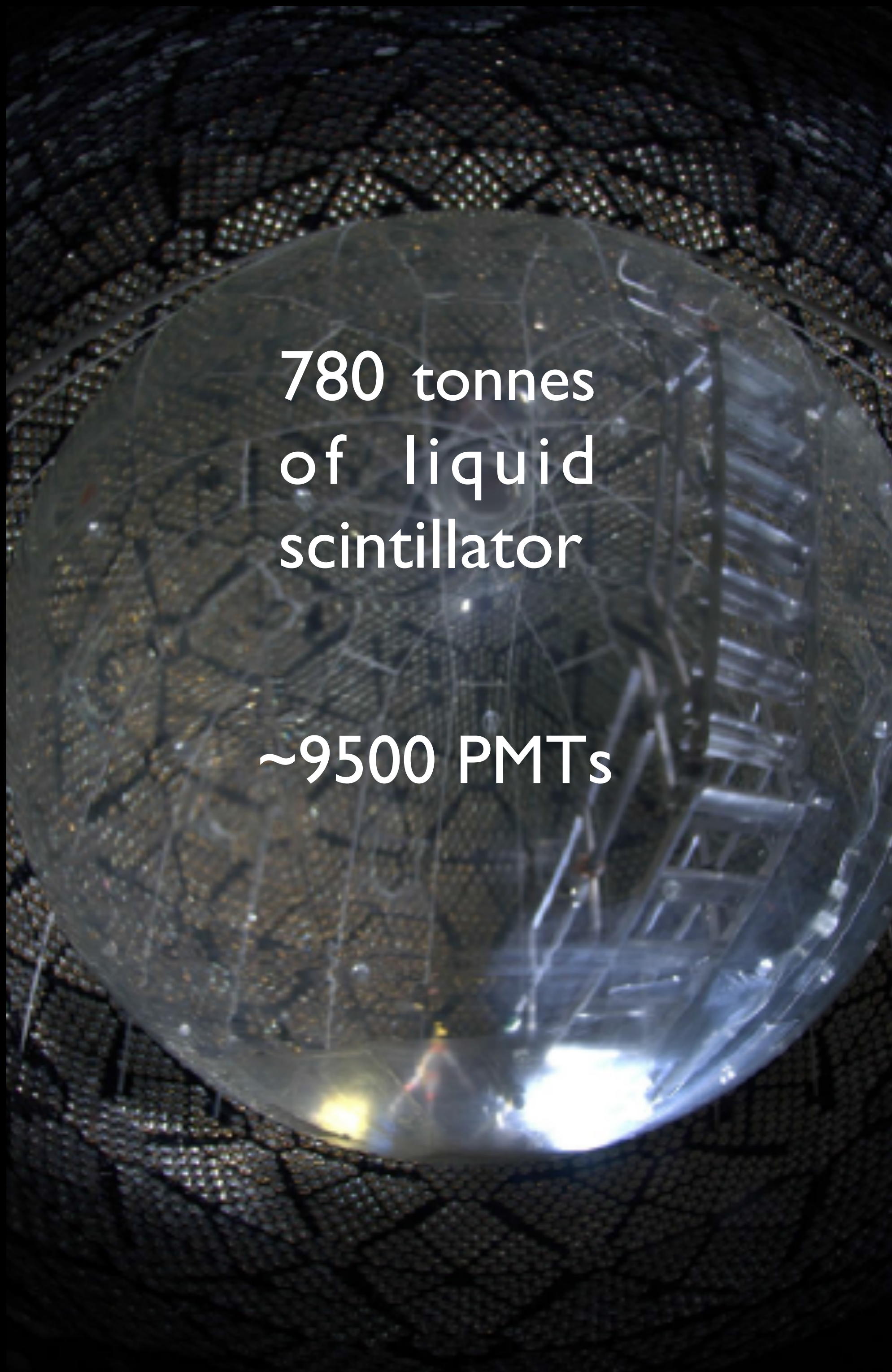


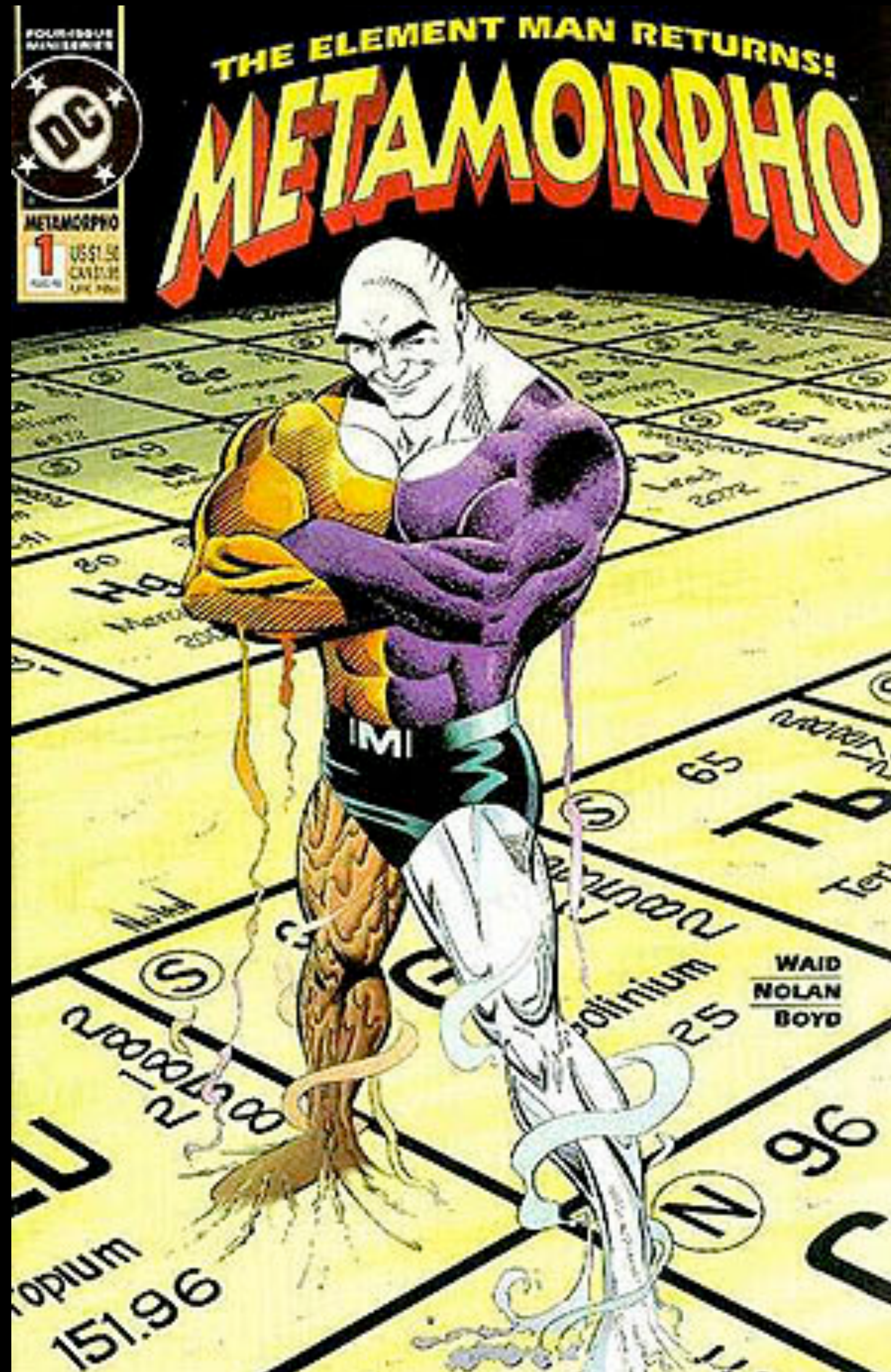
SNO+ with Tellurium

Steve Biller, TAUP 2013


SNOLAB
Aug 15, 2013
Laurentian University
Université Laurentienne



- **Neutrinoless double-beta decay**
- Low energy solar neutrinos
- Geo-neutrinos
- Reactor neutrinos (Δm^2_{12})
- Supernova neutrinos (νp-νp)
- Nucleon decay (“invisible” modes)



Transition to Tellurium

Potential for ^{130}Te as an ideal isotope for a LS-loaded $0\nu\beta\beta$ experiment

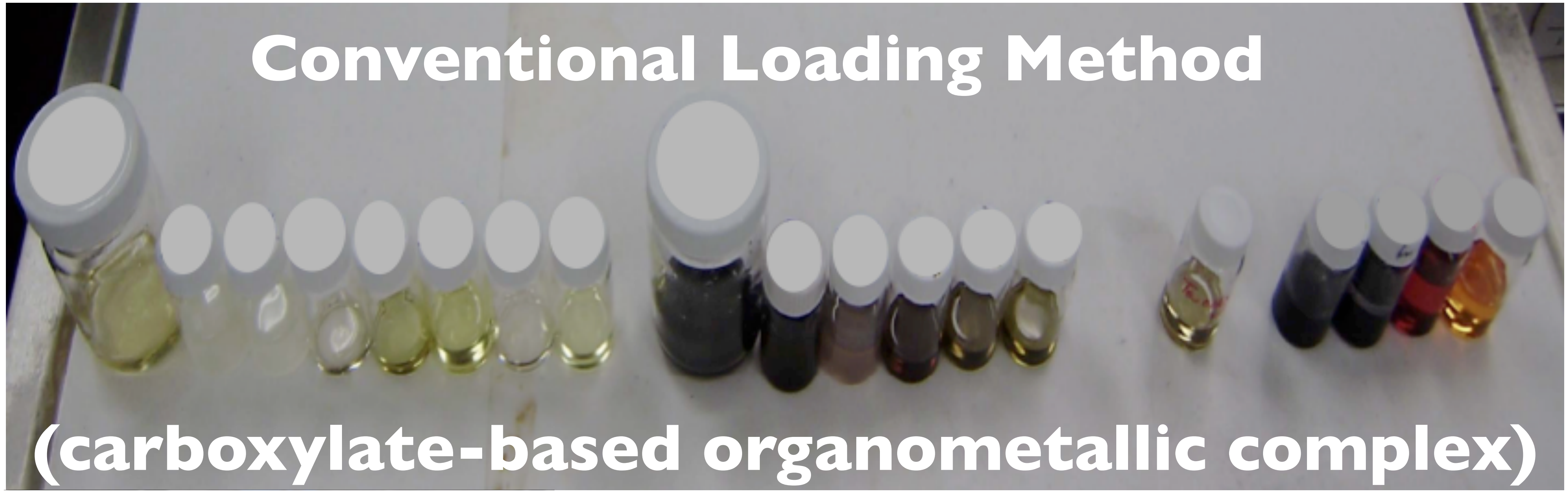
Biller and Chen (Autumn 2011) emphasized potential advantages of Te-loading and initiated development.

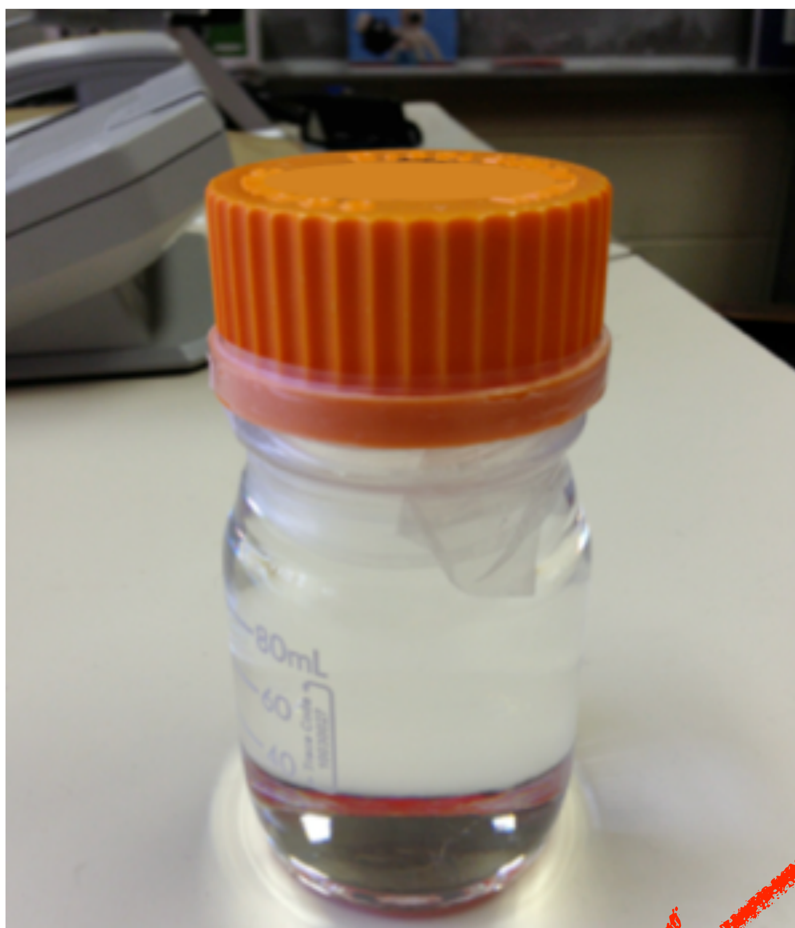
- 34% natural abundance;
- Internal U/Th can be actively suppressed (Bi-Po αs);
- External gammas can be attenuated (“fiducialisation”);
- $2\nu\beta\beta$ rate is low (~100 times smaller than for ^{150}Nd);
- No inherent optical absorption lines;
- Relatively inexpensive (< a tenth the cost of ^{136}Xe).

Initial loading/purification studies by Yeh *et al.* during 2012.

Subsequently underwent thorough, independent internal review from Aug 2012 - Feb 2013. This resulted in the decision to pursue Te as a first priority, which has since been the focus of a full collaboration development effort.

Loading





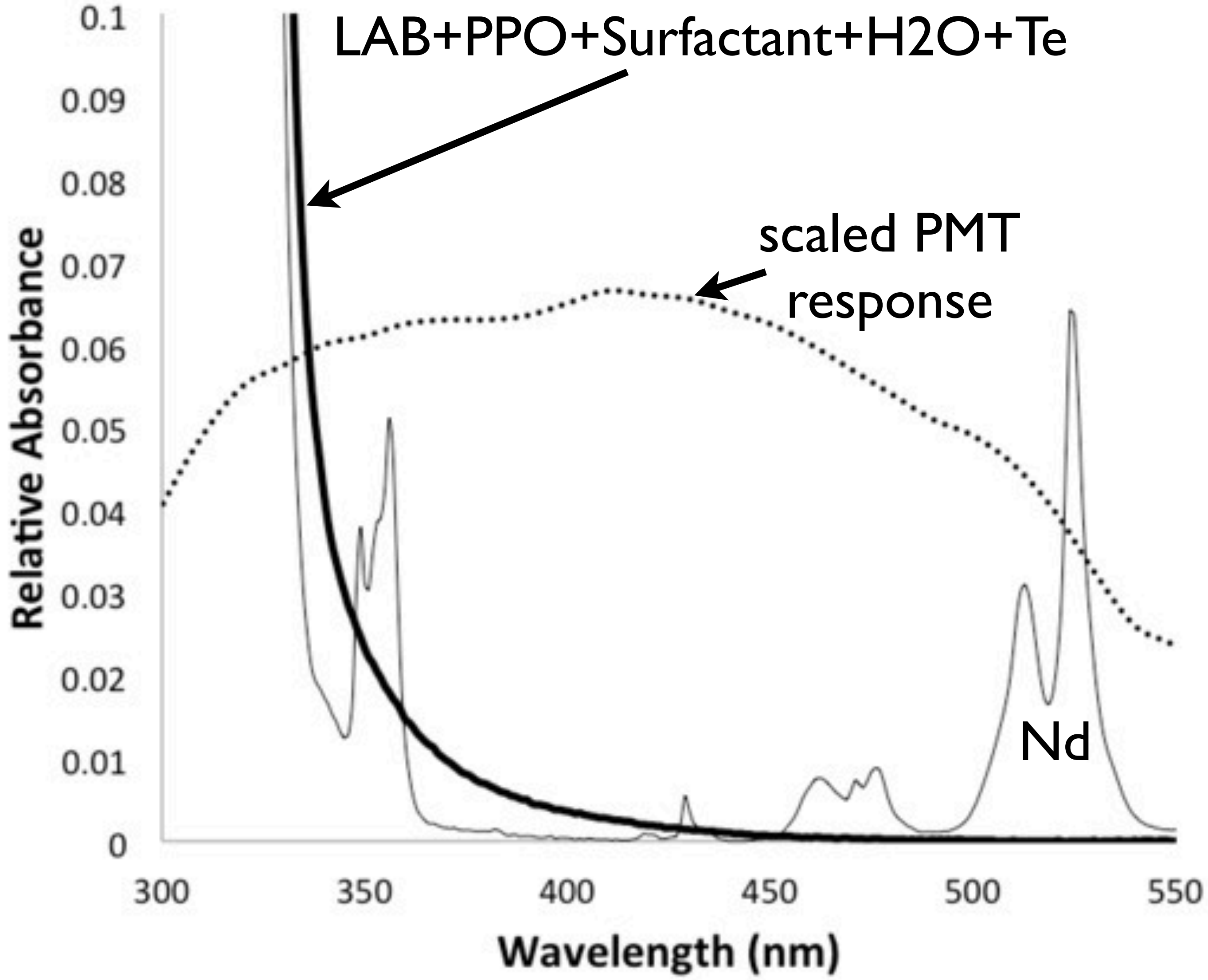
<u>New loading technique (BNL):</u>

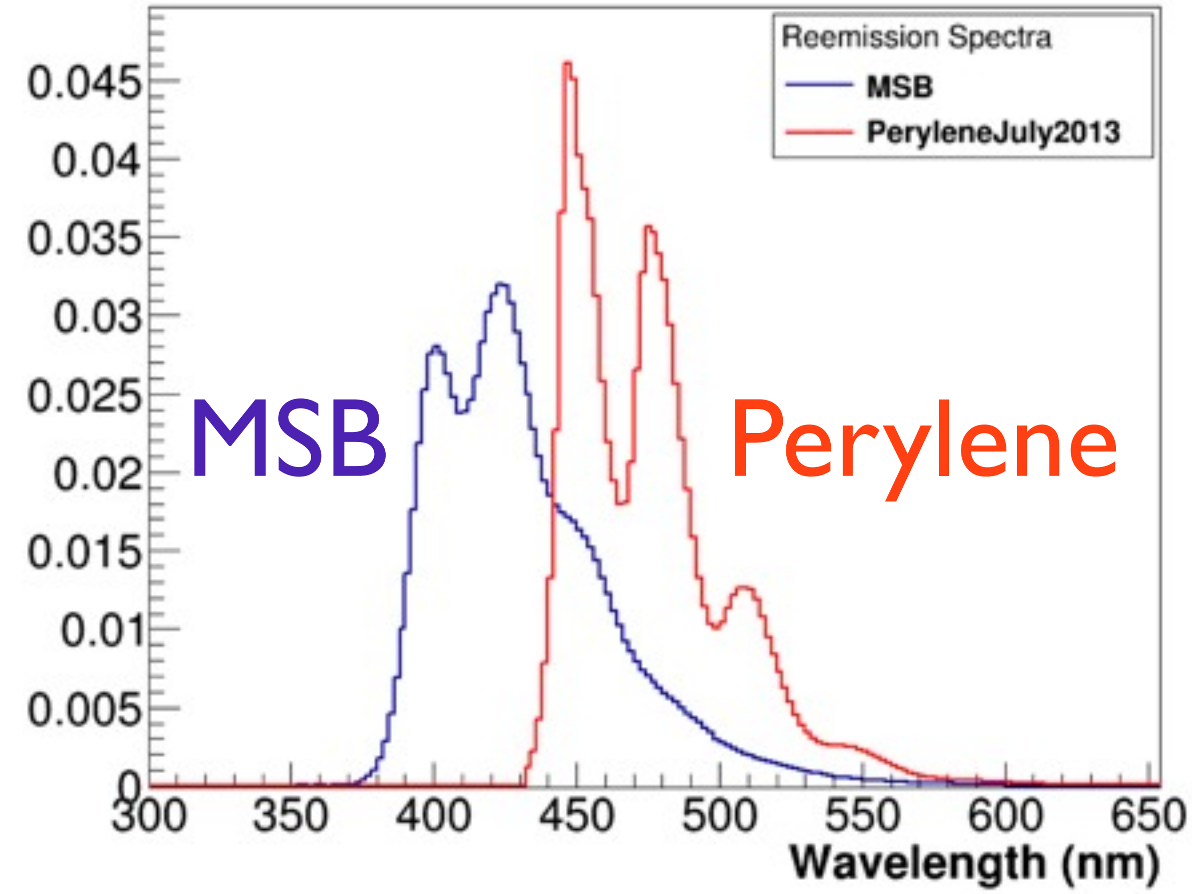
Dissolve telluric acid in water (highly soluble), then combine a small fraction (few percent) of this mixture with LAB using a surfactant. Clear and stable (>1 yr explicitly demonstrated)

(M.Yeh et al., paper in preparation)

Spike tests show metal scavengers reduce U/Th by ~800 in single pass (target is a total reduction of ~10^4)

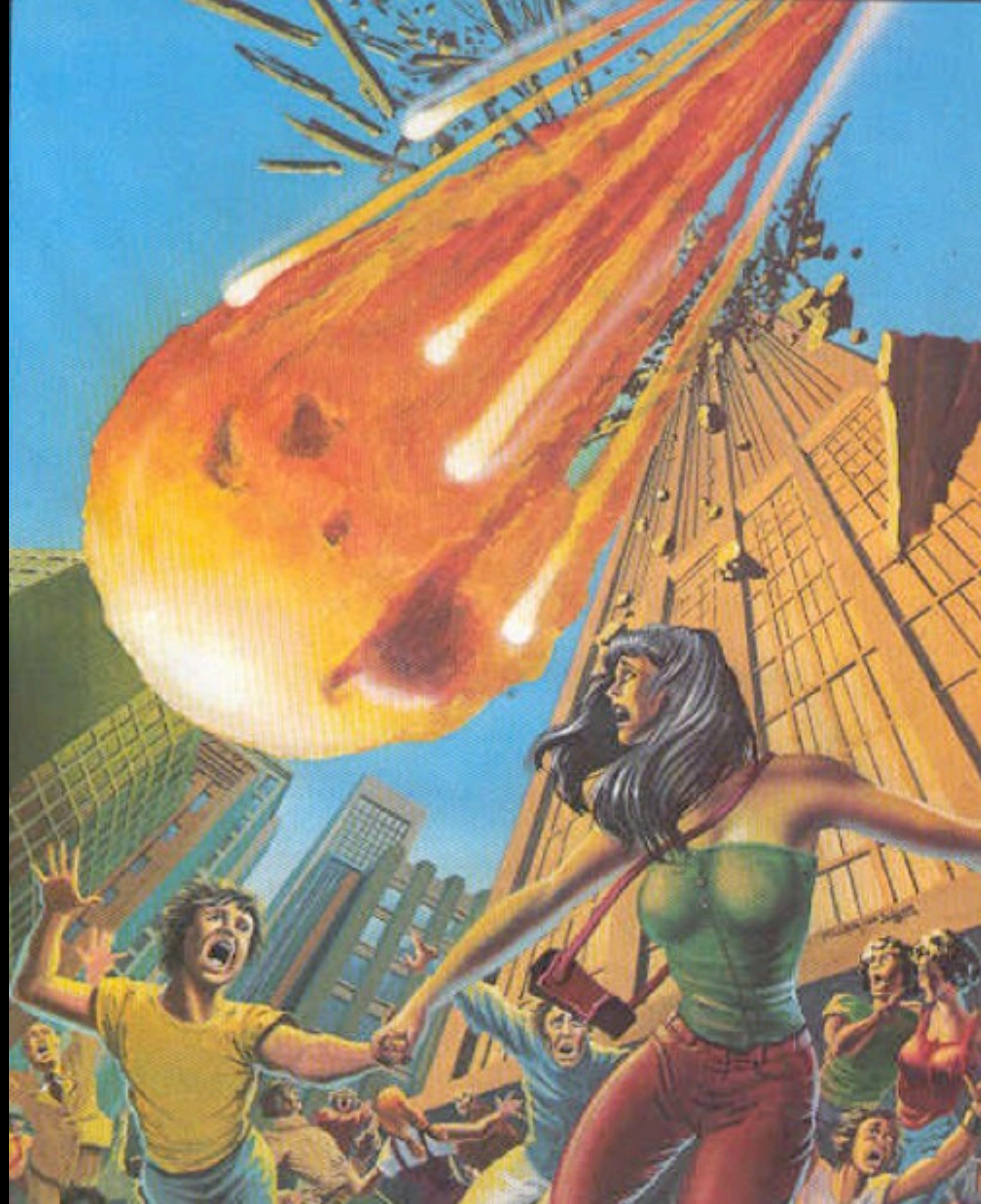
Higher U/Th than pure organic, but still low enough with SNO purification levels (10^{-14}-10^{-15} g/g)





Studies suggest average light levels of ~200-300 pe/MeV*

* Based on multi-component scintillator model extrapolating laboratory measurements of absorption, emission and intrinsic light yield of both the full TeLS mixture and individual constituents. Validity of the model was verified by scaling performance estimates to known scintillator experiments and from an analysis of light production from one liter of scintillator contained in an acrylic container deployed in the SNO detector during 2008.



Cosmogenics

(and other annoyances)

Isotope (Q > 2 MeV, $T_{1/2}$ > 20 days)	$T_{1/2}$ [5] [d]	Q-value [5] [MeV]	R (ϕ from [6][7]) [μBq/kg]	Events/yr in ROI after 1 yr surface exposure
^{44}Sc (daughter of ^{44}Ti)	0.17 (2.16E+4)	3.65	1.19 (0.052)	5.41
^{46}Sc	83.79	2.37	1.97	20.3
^{60}Co (direct and daughter of ^{60}Fe)	1925.27 (5.48E+8)	2.82	0.81 (0.367)	834
^{68}Ga (daughter of ^{68}Ge)	4.70E-2(271)	2.92	3.14 (1.28)	344
^{26}Al	2.62E+8	4.00	0.67	2.20E-4
^{82}Rb (daughter of ^{82}Sr)	8.75E-4(25.35)	4.40	(2.44)	440
^{88}Y (direct and daughter of ^{88}Zr)	106.63 (83.4)	3.62	3.14 (8.11)	3.61E4
^{42}K (daughter of ^{42}Ar)	0.51 (12016.73)	3.53	1.33 (0.24)	10.0
^{56}Co	77.2	4.57	0.13	0.350
^{58}Co	70.9	2.31	1.29	0.252
^{110m}Ag [a]	249.83	3.01	2.34	3.61E3
^{110}Ag (daughter of ^{110m}Ag) [b]	2.85E-4	2.89	(0.03)	48.6
^{106}Rh (daughter of ^{106}Ru)	3.47E-4 (371.8)	3.54	(0.06)	21.8
^{126m}Sb (direct and daughter of ^{126}Sn) [c]	0.01 (8.40E7)	3.69	71.42 (7.87)	8.63
^{126}Sb (direct and daughter of ^{126m}Sb) [d]	12.35 (0.01)	3.67	89.65 (^{126m}Sb)	1.29E4
^{22}Na	950.6	2.84	1.01	1.01E3
^{84}Rb [e]	32.8	2.69	1.29	24.2
^{90}Y (daughter of ^{90}Sr)	2.67 (10519.2)	2.28	2.69 (0.165)	7.90E-3
^{102}Rh (direct and daughter of ^{102m}Rh) [f]	207.3	2.32	11.77 (0.03)	35.9
^{102m}Rh [g]	1366.77	2.46	11.77	69.9
^{124}Sb	60.2	2.90	182.0	1.62E5

ACTIVIA code, cross sections from Silberberg et al. and TENDL-2009 database, flux parameterisations from Armstrong and Gehrels. Variations from using YIELDX code, TENDL-2012 database, and fluxes from Ziegler change estimated rates by up to a factor of two. Consistency also checked against CUORE beam activation study (Wang *et al.*) and KamLAND induced backgrounds.

(V. Lozza, paper in preparation)

Requires a reduction factor of >10^4 for these isotopes, which is also comparable to the reduction required for U/Th in "raw" Te material (ICP-MS: 2-3x10^{-11} g/g)

Outline of Te Purification Strategy

(paper in preparation)

(Stage 1)

2 Surface passes:

- Dissolve $Te(OH)_6$ in water
- Recrystalise using nitric acid
- Rinse with ethanol

>10^4 reduction

Allow up to 5 hr re-exposure to finish & transport UG

(Stage 2)

2 Underground passes:

- Dissolve in warm water (80°C)
- Cool to Recrystalise thermally

>10^2 reduction

(~50% Te "loss" recovered by recycling to surface system)

Spike Tests (Ongoing)

Element	Reduction Factor	Assay Technique
Stage 1 Te purification, single-pass spike test		
Co	1555 $\pm$ 326	XRF
Sb	>243	XRF
Sn	> 167	XRF
Fe	> 100	XRF
Na	> 346	XRF
Sc	> 165	XRF
Ge	> 333	XRF
Y	> 278	XRF
Zr	> 278	XRF
Ag	> 278	XRF
Pb-212	299 $\pm$ 22	$\beta - \alpha$ counting
Bi-212	348 $\pm$ 81	$\beta - \alpha$ counting
Ra-224	397 $\pm$ 20	$\beta - \alpha$ counting
Th-228	390 $\pm$ 19	$\beta - \alpha$ counting
Stage 1 Te purification, double-pass spike test		
Co	3.7×10^5	XRF
Pb-212	$> 10^4$	$\beta - \alpha$ counting
Bi-212	$> 10^4$	$\beta - \alpha$ counting
Ra-224	$> 10^4$	$\beta - \alpha$ counting
Th-228	$> 10^4$	$\beta - \alpha$ counting
Stage 2 (UG) Te purification, single-pass spike test		
Co	12	XRF
Ag	> 20	XRF
Zr	17	XRF

acid-induced recrystalisation + ethanol wash

thermal recrystalisation

Isotope ($Q > 2$ MeV, $T_{1/2} > 20$ days)	Events/yr in ROI after 1 yr surface exposure	After stage 1 purification plus 5h re-exposure	After stage 2 (UG) purification plus 6 months "cool-down"
^{44}Sc (daughter of ^{44}Ti)	5.41	1.80	1.89E-5
^{46}Sc	20.3	0.04	9.30E-5
^{60}Co (direct and daughter of ^{60}Fe)	834	0.511	4.79E-3
^{68}Ga (daughter of ^{68}Ge)	344	0.703	2.03E-3
^{26}Al	2.20E-4	2.63E-7	2.63E-9
^{82}Rb (daughter of ^{82}Sr)	440	2.56	1.74E-4
^{88}Y (direct and daughter of ^{88}Zr)	3.61E4	37.9	0.213
^{42}K (daughter of ^{42}Ar)	10.0	0.90	7.72E-5
^{56}Co	0.350	6.83E-4	1.33E-6
^{58}Co	0.252	5.29E-4	8.88E-7
^{110m}Ag [a]	3.61E3	3.60	0.022
^{110}Ag (daughter of ^{110m}Ag) [b]	48.6	0.05	2.93E-4
^{106}Rh (daughter of ^{106}Ru)	21.8	0.022	1.58E-4
^{126m}Sb (direct and daughter of ^{126}Sn) [c]	8.63	8.58	4.34E-7
^{126}Sb (direct and daughter of ^{126m}Sb) [d]	1.29E4	154	5.44E-5
^{22}Na	1.01E3	0.711	6.22E-3
^{84}Rb [e]	24.2	0.11	2.31E-5
^{90}Y (daughter of ^{90}Sr)	7.90E-3	2.77E-4	1.80E-8
^{102}Rh (direct and daughter of ^{102m}Rh) [f]	35.9	0.044	2.39E-4
^{102m}Rh [g]	69.9	0.060	5.45E-4
^{124}Sb	1.62E5	417	0.509

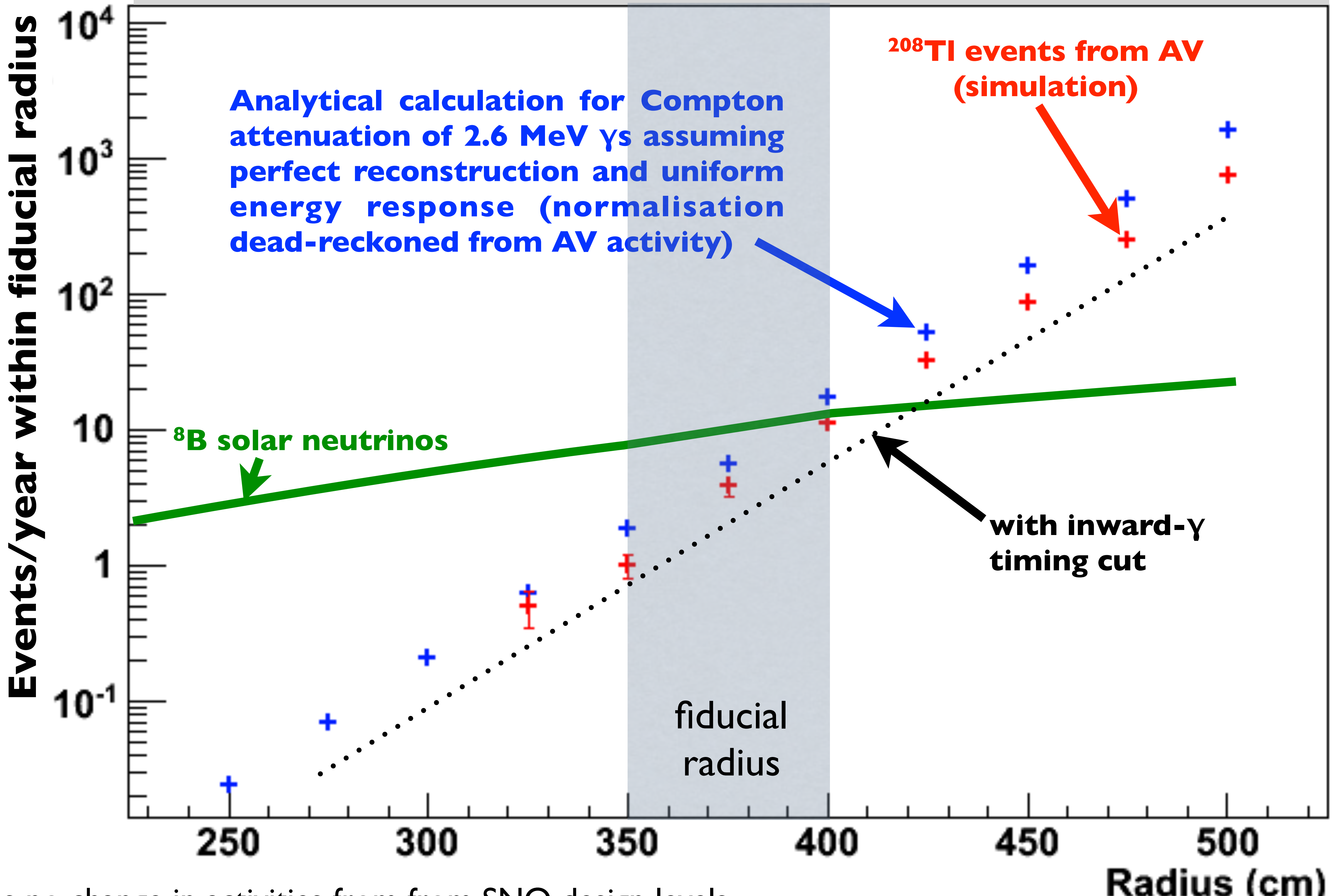
Suppression of Other Troublesome Backgrounds

External γ-ray backgrounds from AV, rope net, PMTs, water shielding etc. are attenuated by Compton scattering (self-shielded fiducial volume)

dominant, due to 2.6MeV γs from ^{208}Tl

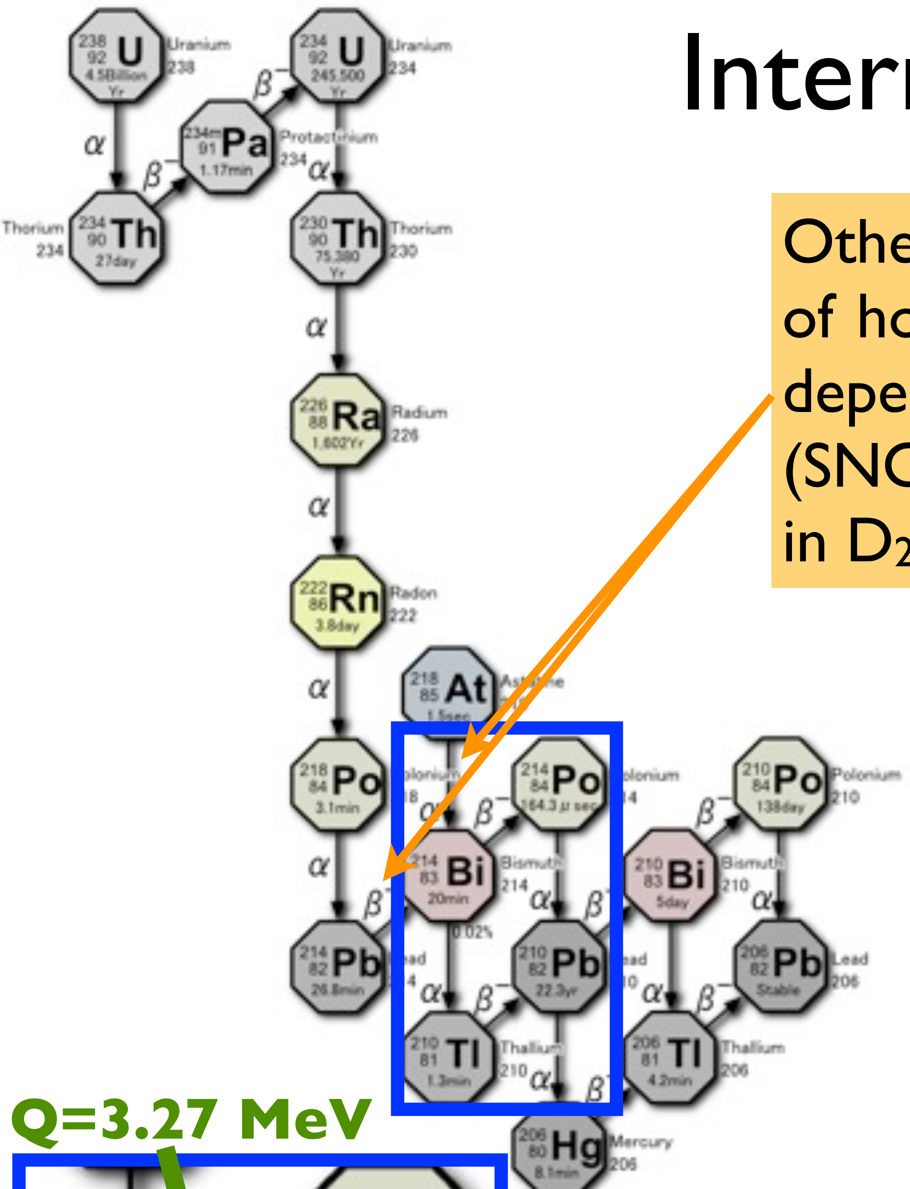
~40% of externals

Backgrounds* from AV ^{208}Tl falling within ROI for 0νββ

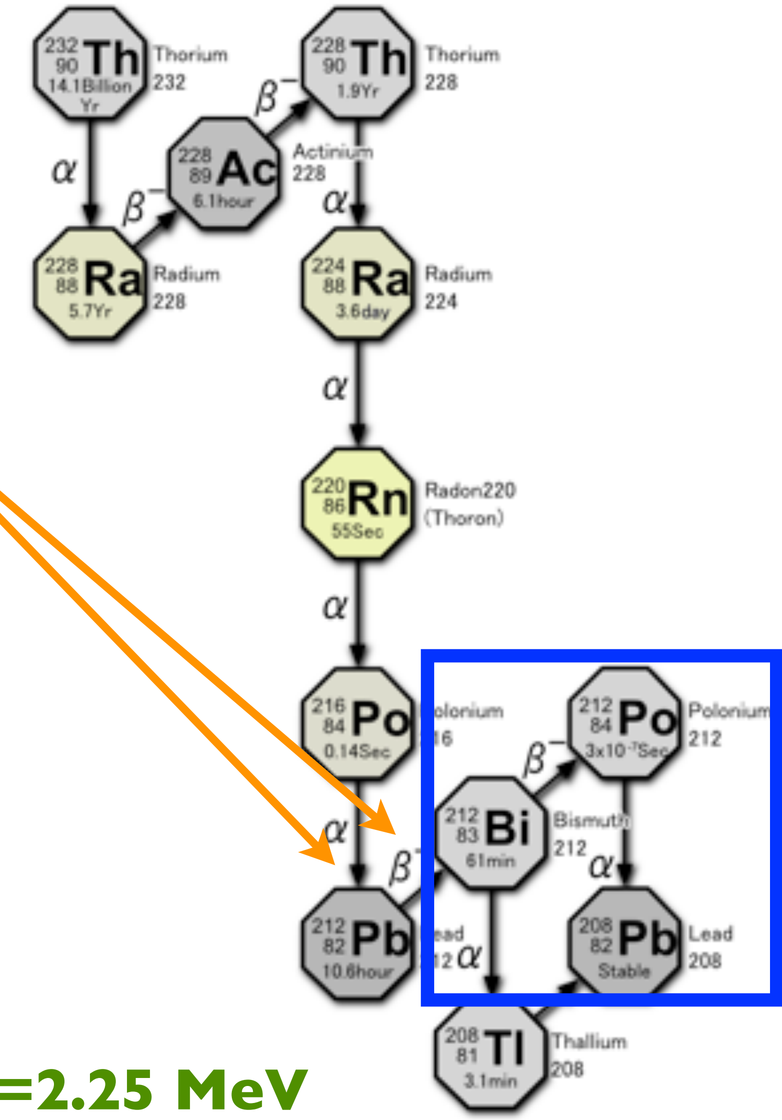


*Assumes no change in activities from from SNO design levels

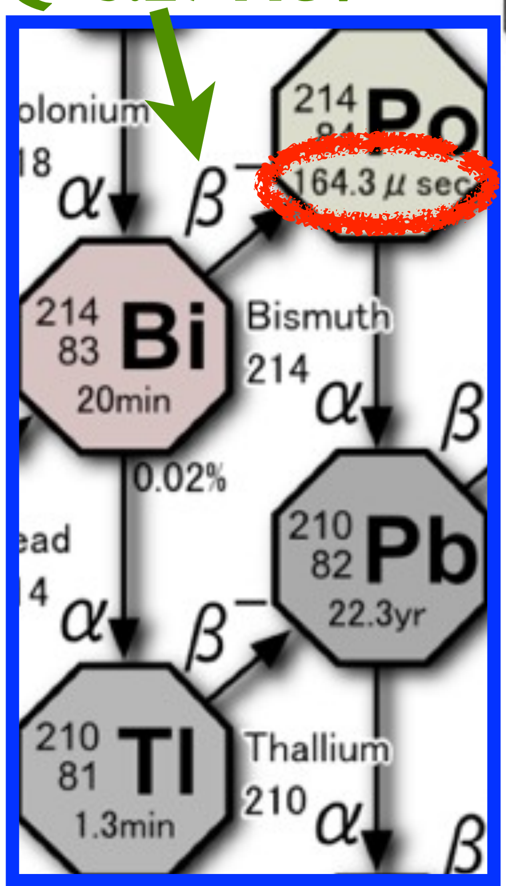
Internal U/Th Backgrounds



Other pre-cursor tags with timescales of hours to days may also be possible, depending on thermal gradients (SNO demonstrated stability over days in D_2O for container-less sources)



Q=3.27 MeV



99.8% rejection from separated coincidences

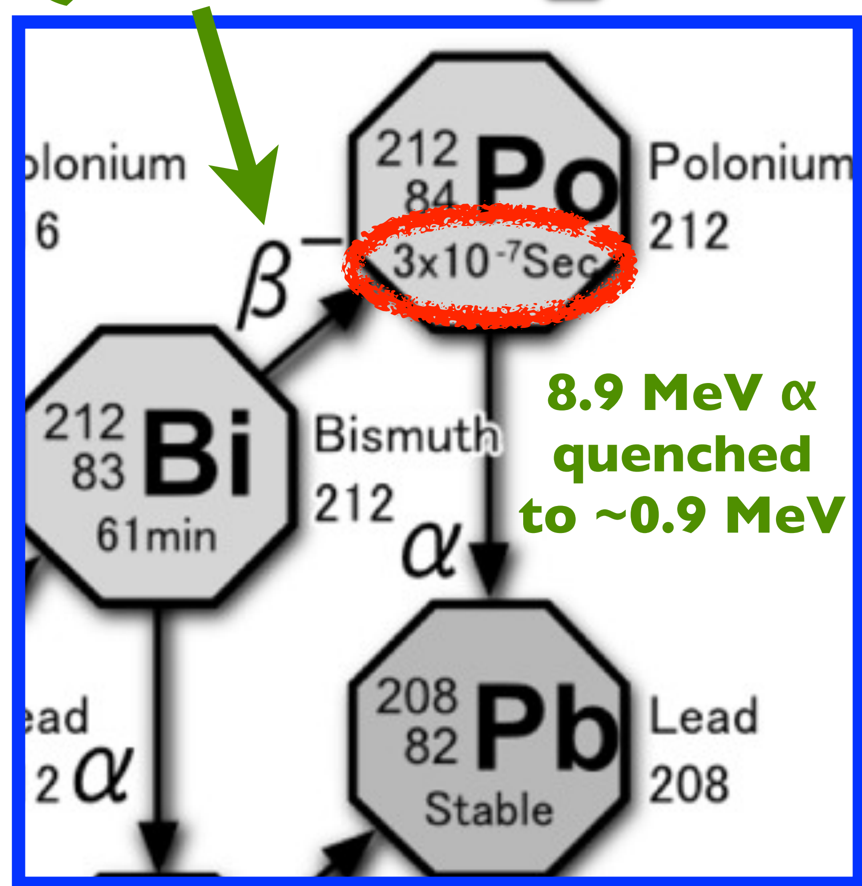
0.2% pile-up

small fraction in ROI

66% pile-up

Further rejection factor in excess of ~50 based on the time-structure in the event window

Q=2.25 MeV



8.9 MeV α quenched to ~0.9 MeV

Sensitivity

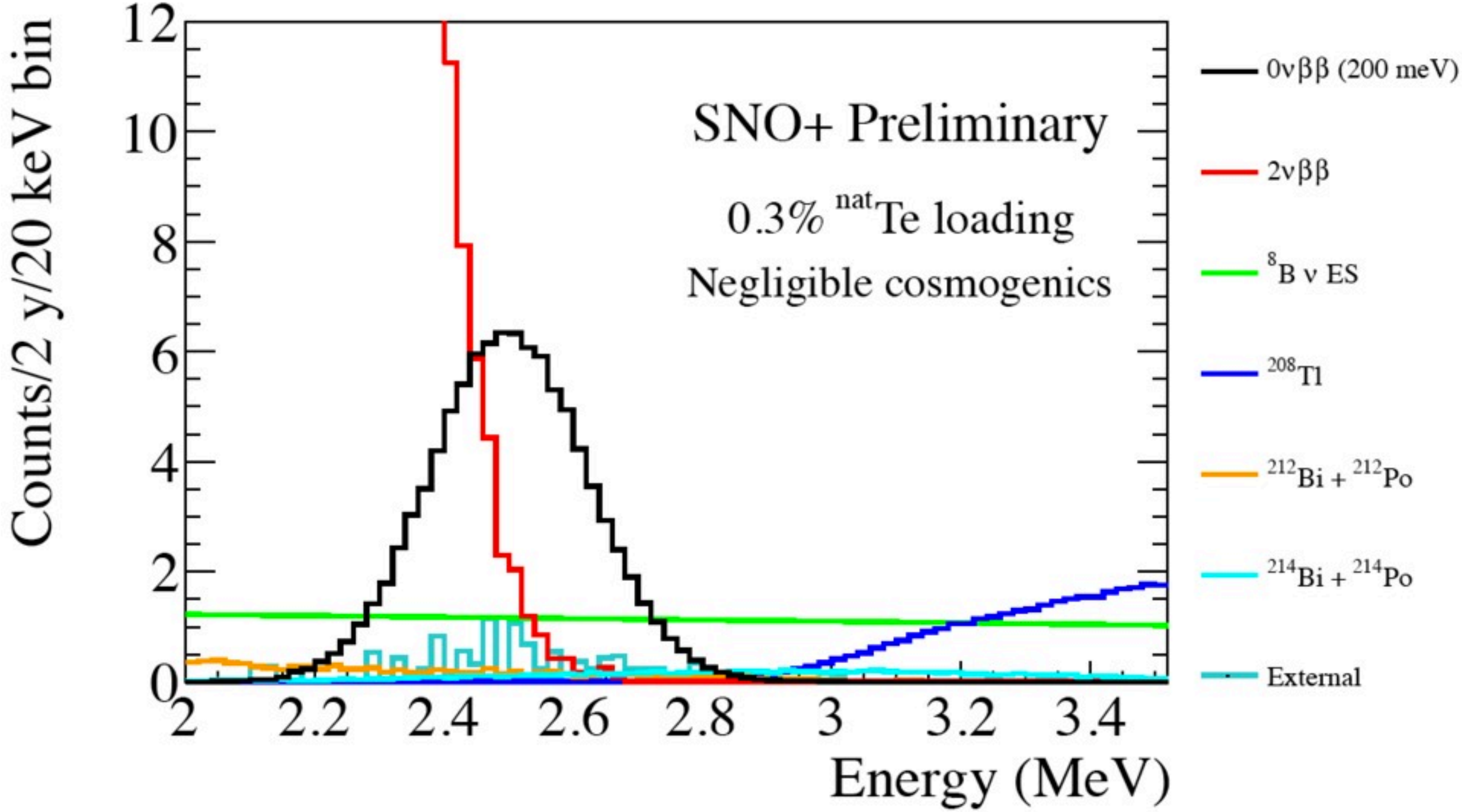
Basic Detector Parameters for Phase I Demonstrator

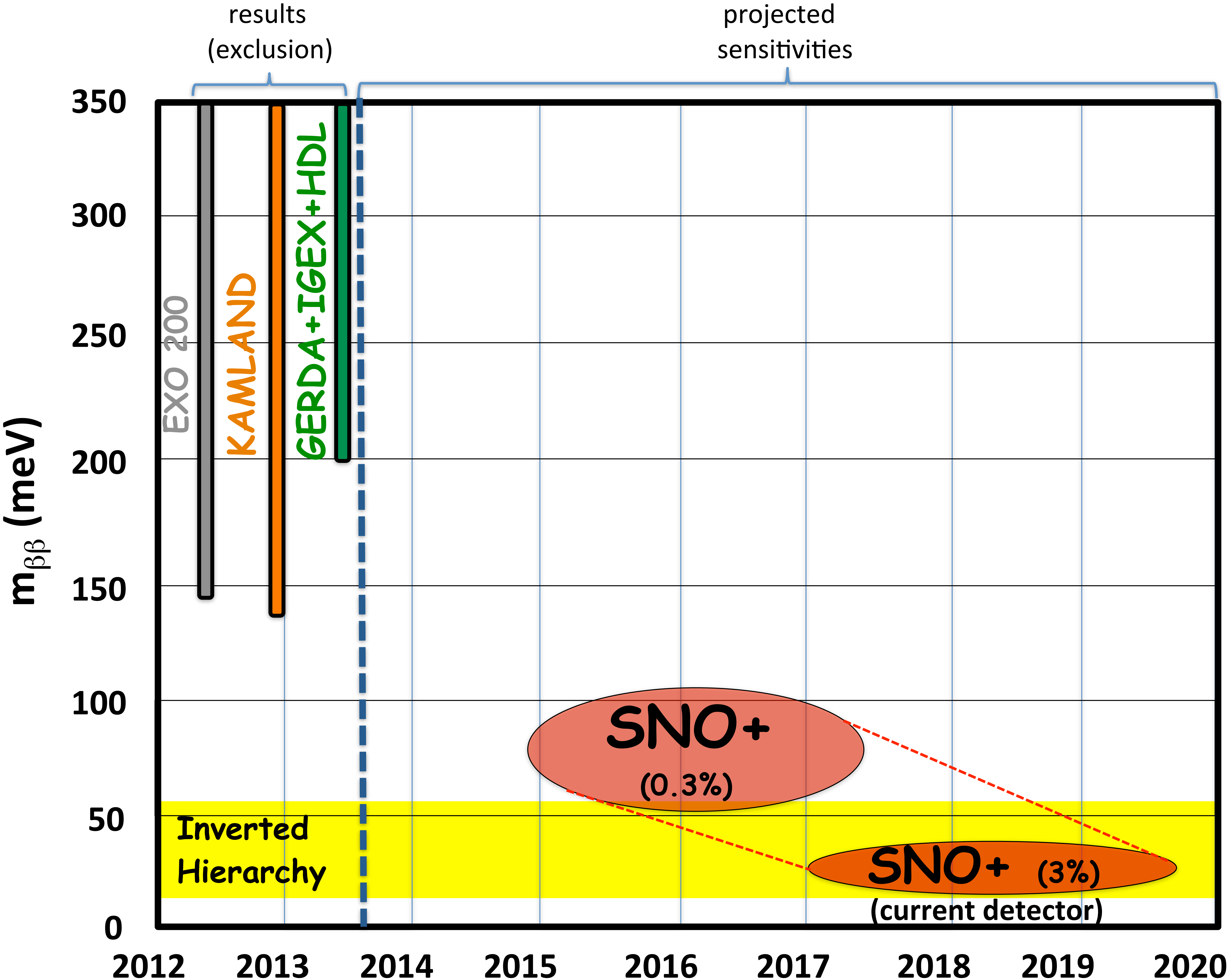
- Light Level: ~200-300 pe/MeV, depending on final optics and choice of secondary shifter. Assume 200 pe/MeV for this talk.

- Loading Level: 0.3-0.5% (0.8-1.3 tonnes ^{130}Te), depending on final Te system resources. Assume 0.3% for this talk.

- Fiducial Volume: 20-30%, depending on light level, loading fraction and final backgrounds. Assume 20% for this talk
(R=3.5m, ~10 times current K-Z fiducial volume)

Expected Average Spectra of Contributing Backgrounds for Two Live Years of Data





results
(exclusion)
projected
sensitivities
350
300
250
200
150
100
50
0
$m_{\beta\beta}$ (meV)
EXO 200
KAMLAND
GERDA+IGEX+HDL
SNO+
(0.3%)
SNO+ (3%)
(current detector)
Inverted
Hierarchy
2012
2013
2014
2015
2016
2017
2018
2019
2020

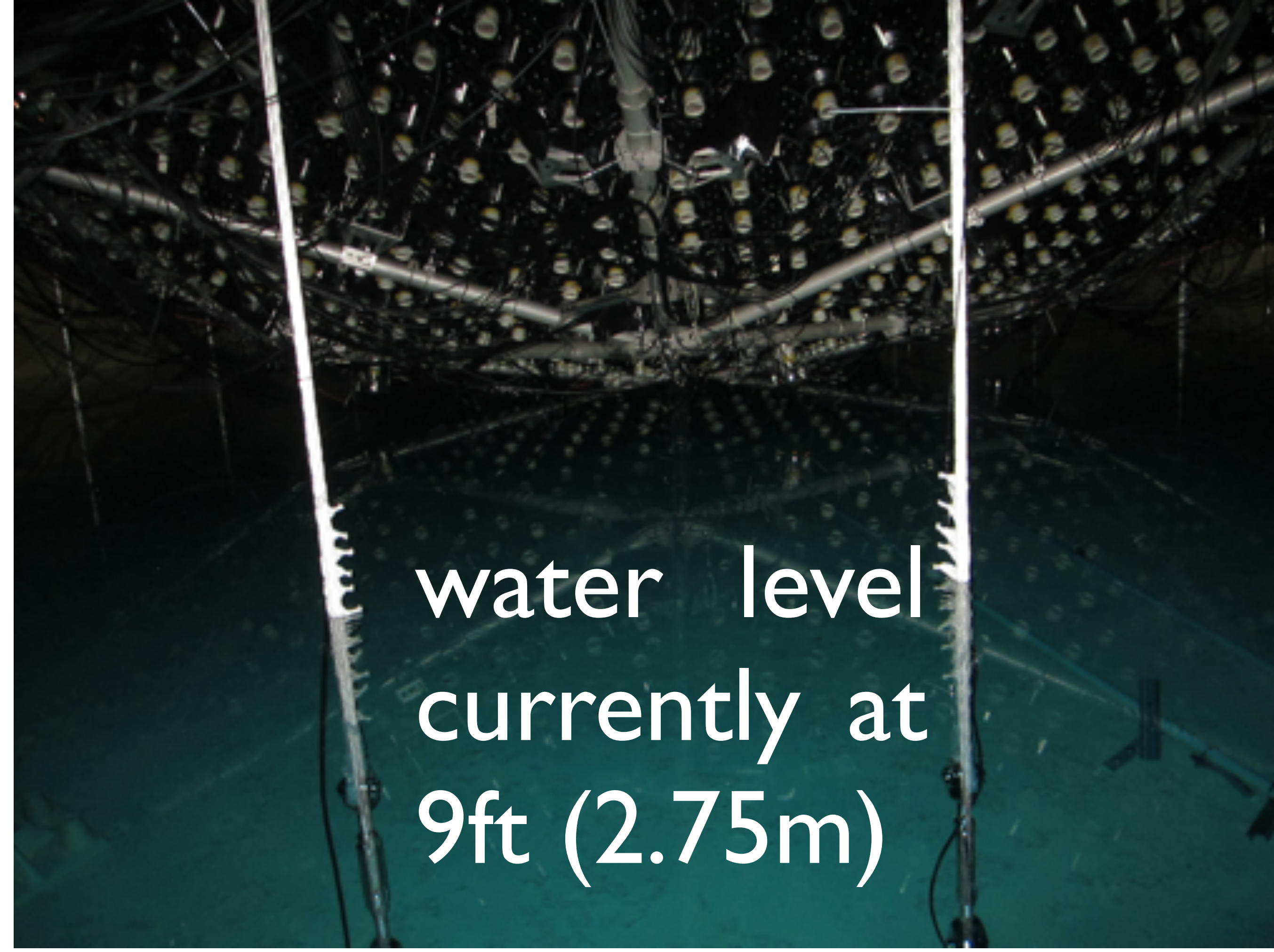
The Pedigree of Bumps

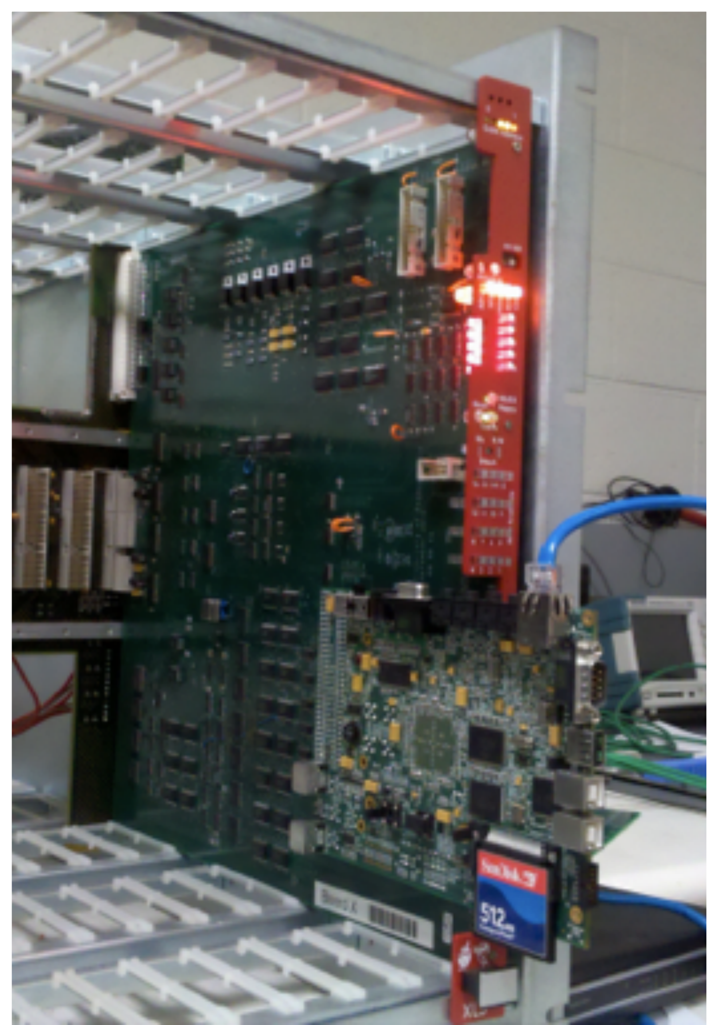
What If We See a Bump?

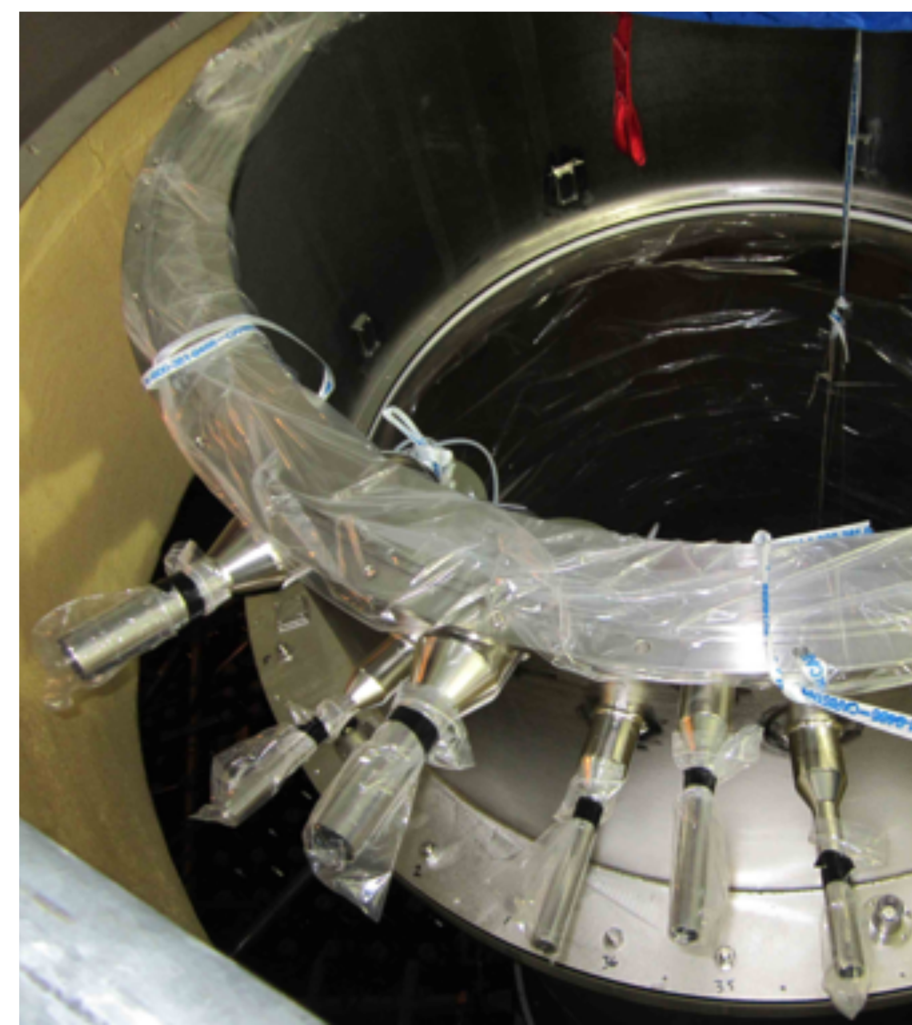
(Advantages of a large, self-shielding, liquid detector with good spatial resolution and a flexible configuration)

- Separately measure backgrounds prior to loading and increase or decreased the loading at later stages to see if it scales like a signal.
- Look at the radial, as well as energy dependence of any potential signal to look for signs of external backgrounds.
- Look for time dependencies of potential radioactive backgrounds.
- Remove Te and run it though additional targeted purification systems to reduce/test for any suspected contaminants.
- If the signal appears to be high enough in mass, could still deploy Nd (or some other isotope) as an independent check.
- Could upgrade detector with high QE PMTs and better concentrators to improve energy resolution and overall sensitivity.
- Other ideas in the works... (Cherenkov light? [Biller, 2013])

Present and Future


water level
currently at
9ft (2.75m)



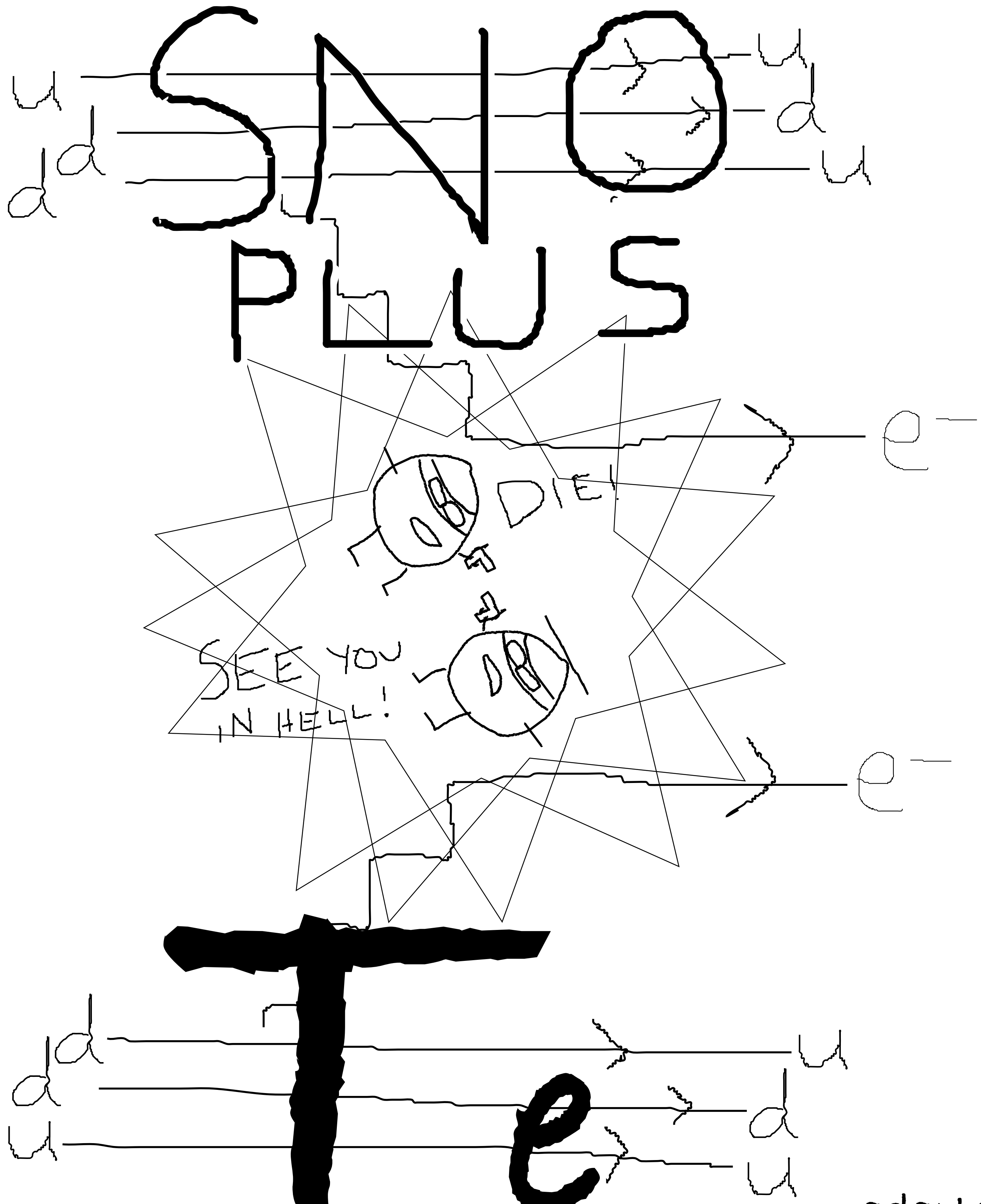


Schedule:

- Water level just below PMTs ("cool and clean").
- "Float the Boat" test: imminent.
- Larger scale $Te(OH)_6$ purification test: imminent.
- Order for initial $Te(OH)_6$ production: imminent.
- Completion of water-fill: end of 2013.
- Water running: start of 2014.
- Scintillator transition: mid-2014.
- Introduction of Te: end of 2014/start of 2015.

Potential for Future Upgrades

- Currently planned Phase I loading is only 0.3-0.5%
- Current peak SNO PMT efficiency is only ~15%
- Current effective photocathode coverage is only ~45%
- Current limiting external background is from the AV
- Current fiducial volume is only ~200 t (full cavity ~7kt)



adapted from
A. Mastbaum
(unofficial logo)